

Decussation as an axial twist: A Comment on Kinsbourne (2013)

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Abstract

One of the great mysteries of the brain, which has puzzled all-time students of brain form and function, are the contralateral organization of the forebrain and the crossings of its major afferent and efferent connections. As a novel explanation, two recent studies have proposed that most of the forebrain is rotated by 180°. Unfortunately, the latter study presented the first one in a misleading manner. We here discuss the similarities and differences between the two hypotheses.

Keywords: body axis, embryogenesis, brain evolution, brain asymmetry, decussation, chiasm, situs inversus

Recently, two studies have independently proposed very similar hypotheses to explain the extensive decussations that exist between the forebrain and the rest of the nervous system of all vertebrates as an axial twist (de Lussanet and Osse, 2012; Kinsbourne, 2013). In doing so, these two studies contributed to a discourse on one of the grand mysteries of the vertebrate body plan which was first initiated by Ramón y Cajal (1899), whose view turned out to be wrong (de Lussanet and Osse, 2012). Although Kinsbourne acknowledged that his thesis is closely related to our axial twist hypothesis, he unfortunately misunderstood some issues of our work. Here we would like to correct the misrepresentation of our hypothesis.

We, like Kinsbourne, hypothesized that the forebrain (except for a small caudal region including the habenulae) of vertebrates is rotated by 180° about the rostrocaudal axis. We too speculated about a possible link to the dorsoventral inversion hypothesis (Geoffroy-Saint-Hilaire, 1822; Arendt and Nübler-Jung, 1994), but in addition we considered alternative evolutionary origins which cannot currently be rejected. In addition to such speculations, however, we also proposed developmental and evolutionary mechanisms for the twist, along with supporting evidence. Briefly, our axial twist hypothesis can be summarized as follows. We proposed that

the vertebrate gastrula lies on its left side. Just prior to neurulation the forebrain-eye region turns 90° clockwise (when facing the embryo). Subsequently, a 90° anti-clockwise turn sweeps over the rest of the body starting from the mid-brain region in a caudal direction, but sparing the heart and other inner organs. Both turns are known in the literature; the latter is very well-known. The sum of the clockwise and anti-clockwise turns makes that the forebrain, eyes and olfactory organ are rotated by 180° along the rostrocaudal axis.

At the time when we published our axial twist hypothesis, we did not know of Kinsbourne's ideas, which was unfortunate because he had already started to develop those in the 1970s (Kinsbourne, 1978). In contrast to his somatic twist hypothesis, our model is the only one that explains the unusual representation of visual information in the forebrain of chondrichthyans such as the shark. In such chondrichthyans the visual pathway decussates twice: at first in the optic chiasm, and then again, after passing the optic tectum, in the tecto-thalamic decussation (Ebbesson and Schroeder, 1971). Finally, our model is the only one that explains the asymmetric location of the heart and some inner organs.

In conclusion, two studies have independently proposed a similar explanation for the major decussations that connect the forebrain to the rest of the nervous system (de Lussanet and Osse, 2012; Kinsbourne, 2013). Except for a few examples

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such as the ones mentioned above, the two hypotheses are anatomically hardly distinguishable. Even from a genetic perspective the two models are similar, but in contrast to Kinsbourne's, our axial twist model is supported additionally by developmental evidence. Both hypotheses are principally compatible with the dorsoventral inversion hypothesis, but differ distinctly in the proposed evolutionary scenario. Whereas Kinsbourne's somatic twist hypothesis proposes a "spandrel", a consequence of an unknown, unrelated evolutionary event, our axial twist hypothesis is very explicit in proposing that it is the evolutionary consequence of a side turn and in this sense presents a clear parallel to the asymmetric development in other deuterostomes such as cephalochordates, tunicates and echinoderms (de Lussanet, 2011).

As a final remark, we would like to mention that we, too, have originally thought of the possibility a single 180° turn of the rostral head region, but rejected this by lack of embryological and fossil evidence and lack of a plausible evolutionary scenario. We therefore developed our double 90°-turn scenario which has all the merits while incidentally solving the mystery of the embryological turning of the inner organs for free.

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